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A review on Electromagnetic fields (EMFs) and the reproductive system

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Abstract

Environmental factors, such as electromagnetic waves, induce biological and genetic effects. One of the most important physiological systems involved with electromagnetic fields (EMFs) is the genital system. This paper reviews the effects of EMFs on human reproductive organs, female animals, fetus development and the importance of two types of natural antioxidants, i.e., vitamin E and fennel. The studies presented in this review referred to the effects of different exposures to EMFs on the reproductive system, and we tried to show the role of natural antioxidants in reducing the effects of the exposures. Many studies have been done on the effects of ionizing and non-ionizing electromagnetic waves on the cell line of spermatogenesis, sexual hormones, and the structure of the testes. Also, about the hormonal cycle, folliculogenesis and female infertility related to EMF have been given more consideration. In particular, attention is directed to pregnant women due to the importance of their fetuses. However, in addition to the studies conducted on animals, further epidemiological research should be conducted.

Keywords: Electromagnetic fields (EMFs), Reproduction system, Antioxidants

1. Introduction

People in the modern world frequently are exposed to electromagnetic fields (EMFs). Human exposure to EMFs comes from many sources, and situations are different in people's everyday lives. EMFs emanate from power lines, computer devices, televisions, radios, and telephones. There are many factors that influence the degree to which people may be affected by EMFs. For example, body weight, body-mass index, bone density, and the levels of water and electrolytes can alter the conductivity of and biological reactivity to EMFs (1, 2). Therefore, the effects of this environmental pollution can depend on gender, tissue density of the body, the period of life, and the exposure levels to EMFs. Beginning in 1960 when the biological hazards caused by EMFs first were studied, human health became an important focus in the workplace and at home (3). Although, the biological effects of EMFs are still controversial, in general, the negative effects should not be ignored. Currently, people are exposed to various types of EMFs, which are non-ionic radiation that cannot release electrons. They are energy in the form of oscillating electric and magnetic fields that are transformed from one point to another. Many forms of physical energy, such as X-rays, UV light, and sunlight produce EMFs (4). There are several references that classify EMFs, but, in general, they can be considered to consist of four different types. The first type of EMFs refers to extremely low frequency (ELF) EMFs, which are EMFs that are below 300 HZ, and they are produced by military equipment and railroads. The second type, known as intermediate frequency (IF) EMFs, have frequencies in the range of 300 Hz to 10 MHZ, and they are produced by industrial cables and electrical equipment in homes, such as televisions and computer monitors. The third type is hyper frequency (HF) EMFs that have frequencies in the range of 10 MHz to 3000 GHz and are produced by mobile phones and radio broadcasting. Radio frequencies (RFs) also are a part of this category, which has frequencies up to 100 MHz (4). There are also static EMFs that are produced by MRI and geomagnetism and have specified with zero frequency (3). In 1979, Wertheimer and Looper showed that there is a direct relationship between EMFs and the increased incidence of leukemia in infants (5). If the body's biological system is exposed to EMFs, which produce electric currents and fields, which, in fact, deal with the current and voltage, the normal physiological balance is upset. If the density of the electric current increases to the stimulation threshold, membrane depolarization of the nerves and muscles may result. Electric and magnetic fields at environmental levels may extend the lifetime of free radicals and result in damage to people's deoxyribonucleic acid (DNA) (6). Some epidemiological studies have been done in various populations, but most have been done in laboratory animals and cell lines (4). The biological effects of EMFs generally can be divided into thermal and non-thermal effects (7). Thermal effects are defined as the heat generated by EMFs in a specific area. The non-thermal effects depend on the absorption of energy and changes in the behavior of tissues without producing heat. EMFs have high penetration power, and they are capable of moving charged particles, such as the electrons and ions of large macromolecules and polymers (7). So EMFs can have devastating effects on tissue with high concentrations of electrons and ions. EMFs that cause changes in the behavior of cells (8) and tissues alter the function of the cardiovascular system (9) and bone marrow (7). Electromagnetic fields can have several different effects on cellular components (10), including disorders of cell proliferation and differentiation (10), damaged DNA in cells, chromosomal abnormalities (11), blood disorders (9), birth defects (12), and various mutations, including those associated with long-term exposure to EMFs. Under the influence of these fields, the balance of the CNS and the hormonal and respiratory systems become weak, resulting in decreased activity of the mentioned organs (13, 14). Research on the effects of EMFs on the endocrine system has focused mostly on melatonin and the derived tryptophan produced by the pineal gland (15). Most of the harmful effects of EMFs act through the protein synthesis process (16, 17). In this regard, enzymes, due to their combination of amino acids, are affected, and their catalytic activity is decreased (4). Studies concerning the cytotoxicicity and genotoxicity effects of EMFs mostly have focused on fibroblasts, melanocytes, lymphocytes, monocytes, and muscular cells in people and on the granolosa cells of rats (18). A declassified 1976 Defense Intelligence Agency report showed that military personnel exposed to non-thermal microwave radiation experienced "headaches, fatigue, dizziness, irritability, sleeplessness, depression, anxiety, forgetfulness, and a lack of concentration (19). A2015 study showed that 2.4 GHz WiFi may be one of the major risk factors for brain tumors and other neurodegenerative diseases (20). Another2015 paper showed that polarized EMF (man-made) was much more active biologically than non-polarized EMF (21). Another paper showed that rabbits experienced heart arrhythmia and increased blood pressure when exposed to 2.4 GHz Wi-Fi (22). A long-term study conducted by Lennart Hardell, a Swedish scientist, on glioma and acoustic neuroma brain tumors showed that RF is carcinogenic. The scientist called for RF to be labeled an IARC Class 1 Carcinogen and recommended urgent revision to safety guidelines (23). A 2011 study by Nora Volkow showed that radiation from cell phones, in areas next to the antenna, increased the metabolism of glucose in the brain. Increased metabolism of glucose is associated with cancer. The study showed that biological changes occur at levels lower than the current FCC guidelines (24).

2. Discussion

2.1. Male genital system and EMFs

The destructive effects of EMFs on both genders were studied at different exposures (25). Since the reproductive system is controlled by the nervous and endocrine systems, environmental pollutants, such as EMFs, can affect the two systems mentioned above, so the genital system also is involved (4). The studies on relationship between female rats and neurorndocrine changes showed that neuroendocrine disorders is the main reason in fertility problems (26). A 2015 study showed that exposure to 2.4 GHz Wi-Fi decreased sperm function. The researchers concluded that "There should be major concern regarding the exposure to Wi-Fi networks existing in the vicinity of our living places."(27). EMFs induced cell death in testicular germ cell in mice (28). In 2004, the negative effects of EMFs were shown to include changes in serum levels of testosterone (29–31). A study of testicular tissue showed that the number of cells in the spermatogenesis cycle was reduced significantly (32). Research reports on the epididymis, seminal vesicles, and prostate gland in prenatal rats exposed to EMFs showed that these animals, at the age of four months, had no changes in sex hormone levels or sperm count (4). A code division multiple access (CDMA) of EMFs with 84 MHz frequency did not significantly affect body weight, testis, epididymis, sperm count, or apoptosis germ cell in adult rats (33). Also, adult rats that were exposed to 900-MHz EMFs for 30 min five days a week had no significant change in the weight of their testes or the relative percentage of the overall context of testicular interstitial tissue, but they had decreased serum levels of testosterone with no changes in their Luteinizing hormone (LH) and Follicle-Stimulating hormone (FSH) levels (34). In rats exposed to 1.95-GHz EMFs for five hours a day for five weeks, there were no observed changes in the tissue and parameters of the reproductive system, but their sperm counts increased irrespective of any abnormalities (4). At high frequencies, especially 2.45 GHz, EMFs reduced the number of leydig cells and increased apoptosis at seminiferous tubule in rats (35). A 2.45 MHz frequency of RF leads to failure in DNA cells of the testes (36). Also, exposure to RF (900 MHz–1.7 GHz) caused DNA breaks in embryonic stem cells and epididymal spermatozoa of mice (34). A 60 Hz and 0.5 T of EMFs caused spermatogonia apoptosis and induced damage to DNA, but there was no significant change in the percentage of living cells (37). RF radiation can reduce sperm fertilization in men (38). Conversely, SLF-EMFs had no effect on the viability and morphology of boars' sperm, but intracellular calcium levels were reduced compared to the control group, and there was reduced motility and fertilization (4). In rabbits, a 50 Hz of SLF-EMFs can cause changes in sperm's motility and reduce their viability (39). This process takes place by interfering with the intracellular calcium homeostasis, resulting in disability in sperm function. Researchers have shown that sperm function was reduced by EMFs (1 mT intensity) in vivo (40). A study of male rats indicated that a 50-Hz frequency for 8 h/day for eight months caused histological variations of the testes that included weight loss and a reduction in the average diameter of the seminiferous tubule (4). In one study with a light microscope, it was observed that in 50-Hz EMFs, spermatogonial cells separated from the germinal epithelium. This study showed that the number of mature spermatozoa in the seminiferous tubules was reduced, and some of the sertoli cells had been flattened (41). All of the reports mentioned the effects of EMFs on the ultra-structure tissue of the male reproductive system in human and animal models. But for further clarification, research must be conducted on the signaling pathways and the molecular structure of the cells.

2.2. Female genital system and EMFs

The female reproductive system is a set of different tissues that are related together. So, if EMFs' effects on female infertility are discussed, the effects of this environmental factor must be evaluated on the different parts of the genital system. The female genital system is composed of the uterus, ovaries, fallopian tubes, the released oocysts, and germ and somatic cells in their tissue. According to many researchers, neuroendocrine changes caused by EMFs are a key factor in changing hormone function and cause infertility symptoms in females (26). A number of other researchers have focused on the estrous cycle (42). One of the differences between women's and female rodents' sexual cycles is that women's cycles are complete, and the peak of estrogen-progestrone is separated. In female rodents, the peak of these two hormones is concurrent. So perhaps, the peak of estrogen-progestrone should be considered for future investigation. Besides, a lot of research has focused on the harmful effects of EMFs on the granulosa cells of the oocytes. Apoptosis of these cells is also another issue in many articles (43). In the following, several reports regarding this are presented. Spontaneous abortion and fetal abnormalities are two interrelated issues that have attracted the attention of many researchers (44). Clinical studies on pregnant women exposed to Video display terminal (VDT) have indicated a significant increase in spontaneous abortions (45). A positive correlation exists between the occupational monitors with pregnant woman and the ratio of fetal abnormalities (45). Epidemiological studies on birth defects and miscarriages by employed pregnant women indicated that the EMFs generated computers can have negative effects on the reproductive system of people (46). Although, the negative effects on fetal development are controversial, some destructive factors have been reported in many animal models (4). The male offspring of female rats after their exposure to 60Hz frequency, 1mT intensity of SLF-EMFs indicated that there were reductions in the number, height, and volume of seminiferous tubules and in the number and diameters of leydig cells (47). However, serum levels of testosterone, gonadosomatic index, and sertoli cells remained unchanged (47). In contrast, when pregnant rats were exposed to SLF-EMFs (60 Hz frequency, 500 μT intensity) for 21 hours per day, the fertility power and spermatogenesis period of male offspring were not significantly decreased in the experimental group compared to the control group (48). Another study to determine the relationship between EMFs and ovulation in rats showed that the waves inhibited ovulation and reduced the number of corpora lutea (49). Female mice exposed to 20 KHz EMFs from TVs and PCs had extended estrous cycles, which is one of the most important factors in reducing the pregnancy cycle in female animals (50). EMF exposures cause reproductive and a developmental toxicity effect that degenerates oocytes in mice (31). The cultured follicles in the mouse after exposure with 33 Hz SLF-EMFs caused to growth defeat (4). In contrast, exposure to 55 Hz causes the continued growth of the follicles (51). Another research showed that exposure to 33–50 Hz for three days prevented the formation of antral follicles in vitro (51). Adult female rats that were exposed by 50-Hz frequency of SLF did not have significant changes in the weight of uterus, ovaries, and progesterone and estrogen levels (52). After removal of the uterus in female rats and exposure to 1.439 MHz of EMFs (TDMA) for 4 h/day, there were no differences in the uterine volume and steroids hormone levels (53). When female rats were exposed to 900 MHz for 30 days, endometrial apoptosis and oxidative stress increased (54). The effects EMFs on implantation and fetal development have been reported. During mating, mice exposed to 50 Hz frequency, 0.5 mT intensity for 4 h/day for two weeks had significant reductions in the number of blastocysts and increases DNA fragmentation (55). This study suggested that exposure to EMFs in the implantation period can have deleterious effects on the development of embryos. Radiation for 4 h before ovulation showed that SLF-EMFs have negative effects on the early development of the embryo (4). When pregnant mice were exposed to 50 Hz frequency, 20 mT intensity, the survival rate, gender ratio and fetal malformations did not change significantly, but the height and weight of the fetuses increased significantly (56). A study on the effects of EMFs on female rats as analyzed by a transmission electron microscopic (TEM) showed an increase in the number of macrophages and autophagy vacuoles in some granulose cells and the presence of several lipid drops in the luteal and theca cells (56). Other researchers have shown that EMFs cause increased macrophages in the lutea corpora and the growing follicles. They believed that EMFs accelerate the process of apoptosis in ovaries of rats. In addition, most researchers believe that EMFs, through apoptosis, cause the destruction of the ovarian cortical tissue, luminal epithelium, glandular epithelium, and stromal cells in the uterus and fallopian tubes (57).

2.3. Antioxidant definition

Usually, aerobic organisms have different defensive systems or anti-oxidative mechanisms to counteract the damage caused by Reactive oxygen species (ROS) and their products. These defense mechanisms act by preventing the chain reaction initiated by ROS or by breaking the chain reaction after its initiation. Antioxidants are compounds that contain monohydroxy/polyhydroxy phenol, and they are divided into three groups, i.e., 1) primary antioxidants that prevent the formation of oxidants; 2) secondary antioxidants that repair the oxidized molecules through dietary or consecutive antioxidants; and 3) preventive antioxidants, i.e., antioxidants that bind metal macromolecules (albumin, ceruloplasmin and transferrin) and antioxidant enzymes. Consecutive antioxidants consist of lipid-soluble soluble vitamin E, ubiquitone, β carotene, water-soluble GSH, ascorbate, and urate. Antioxidants are essential in preventing heart disease, cancer, and diabetes (88). Cells have many antioxidants that protect them against damage. Prevention of excessive ROS and repair of cellular damage is essential for a cell's life. In this review, we present two examples of natural antioxidants that have been recorded in many studies, i.e., vitamin E and fennel extract.

2.4. Antioxidant properties of Vitamin E

Vitamin E is the most important fat-soluble antioxidant that is located in the fat of the cell's membrane, and it protects the unsaturated phospholipids membrane from free radical and reaction oxidation (54). A natural form of vitamin E is d-alpha tocopherol. Vitamin E eliminates free radicals through converting them into harmless metabolites. The most important activities of vitamin E are that it improves the regenerative cycle, increases elasticity, and increases the body's tolerance. The absorption of vitamin E depends on the function of the pancreas and bile secretions. This vitamin is transferred by lipoproteins plasma and erythrocytes. Cellular uptake of vitamin E occurs through two mechanisms, i.e., 1) a receptor-mediated process in which LDL delivers the vitamin to the cells and 2) The lipoprotein-mediated process that separates vitamin E from chylomicrons and VLDL. Vitamin E is one of phenolic antioxidants, and deficiencies in this vitamin can lead to adverse physical effects. Generally, vitamin E deficiency puts at risk the neuromuscular, cardiovascular, and genital systems. Vitamin E has a significant impact on reducing fetal abortions. The positive impact of vitamin E on the anatomical and histological aspects of the genital system has been shown in numerous studies (59, 60).

2.5. Antioxidant properties of Fennel

Fennel is in the parsley (Apiaceae) family, and it grows naturally in Europe and the Mediterranean region; now, it is cultivated throughout the world. Usually, two species of this plant are edible, i.e., bitter and sweet fennel. It has applications in traditional medicine. In ancient China and Egypt, it was used to treat snakebites, as a food, and for medical purposes. Fennel oil has antioxidant, antimicrobial, antispasmodic, and gastrointestinal stimulant activities (61). Allergic reactions to it occur very rarely. Vitamin C is the most active component of fennel, making up 17% of it. Therefore, it has anti-inflammatory properties, and, due to its fibers, it prevents the transmission of toxins in the colon. In addition to fibers, fennel contains calcium, magnesium, copper, and phosphorus ions (61). Anethole is the most basic fennel compound that reduces inflammation and prevents cancer (62). Anethole also protects the liver against damage. Researchers ascribe the anti-inflammatory and anti-cancer properties of fennel to postpone or off the intra cellular signaling pathway called TNF (63). Thus, fennel can inhibit alterations and eliminates inflammatory cascade molecules called NF-Kappa B (63). Fennel induces the estrous process in female rats. Fennel dramatically increases the number of antral, graphian, and multi-layer follicles and improves the follicugenesis process in the ovaries of mice (61). Since follicular growth is affected by endocrine hormones (FSH, LH, Prolactin and paracrine factors), the estrogenic effects of fennel may increase the number of follicles that are growing (61). Another active ingredient of fennel is diosgenin, which is essential for the synthesis of some hormones. Diosgenin is used for the treatment of osteoporosis in adult rats (64). Malini indicated that seed extract of fennel has estrogenic activity in male and female reproductive organelles and increases the weight of the genital system (65). Oral injection of fennel in rats for 10 days increased the weight of their mammary glands, oviducts, endometria, myometrial, cervixes, and vaginas. Oral gavages fennel increases the concentration of total protein in the seminal vesicles and prostate of male rats. Fennel oil affects uterine contractions and causes a significant reduction in the intensity of contraction induced by oxytosin and E2 prostaglandin (66). This indicates that the antioxidant compounds in fennel and vitamin E, with other antioxidants, can reduce the harmful effects of EMFs on the reproductive system.

3. Conclusions

Many studies have shown that electromagnetic fields can have destructive effects on sex hormones, gonadal function, fetal development, and pregnancy. So people must be aware of the negative effects of EMFs. Although the impact of the waves varied at different frequencies, it is better to stay as far away as possible from their origin because of the risks associated with exposures to these waves. In addition, people can use of natural antioxidants to help reduce the effects of these waves.

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